Chapter 9
Roller-Compacted Concrete Gravity Dams

9-1. Introduction

Gravity dams built using the RCC construction method, afford economies over conventional concrete through rapid placement techniques. Construction procedures associated with RCC require particular attention be given in the layout and design to watertightness and seepage control, horizontal and transverse joints, facing elements, and appurtenant structures. The designer should take advantage of the latitude afforded by RCC construction and use engineering judgment to balance cost reductions and technical requirements related to safety, durability, and long-term performance. A typical cross section of an RCC dam is shown in Figure 9-1. RCC mix design and construction should be in accordance with EM 1110-2-2006.

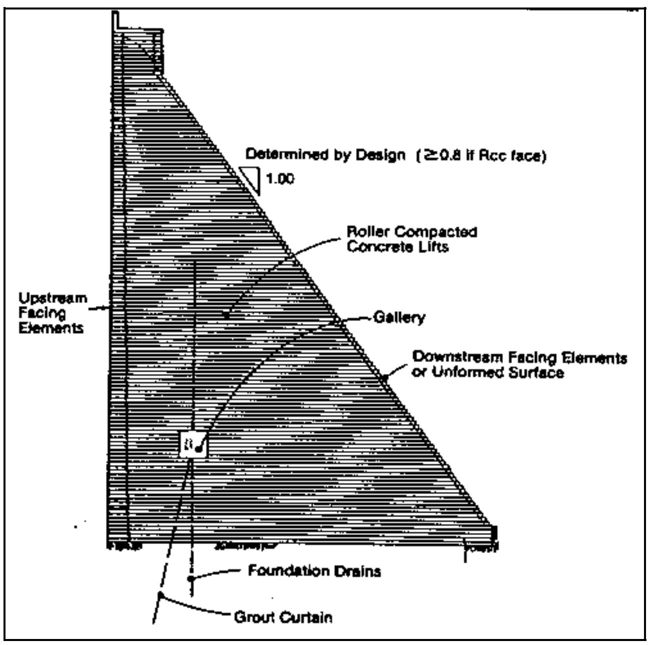

Figure 9-1. Typical RCC dam section

9-2. Construction Method

Construction techniques used for RCC placement often result in a much lower unit cost per cubic yard compared with conventional concrete placement methods. The dry, nonflowable nature of RCC makes the use of a wide range of equipment for construction and continuous placement possible. End and bottom dump trucks and/or conveyors can be used for transporting concrete from the mixer to the dam. Mechanical spreaders, such as caterpillars and graders, place the material in layers or lifts. Self-propelled, vibratory, steel-wheeled, or pneumatic rollers along with the dozers perform the compaction. The thickness of the placement layers, ranging from 8 to 24 inches, is established by the compaction capabilities. With the flexibility of using the above equipment and continuous placement, RCC dams can be constructed at significantly higher rates than those achievable with conventional mass concrete. A typical work layout for the RCC placement spreading operation is illustrated in Figure 9-2.

9-3. Economic Benefits

RCC construction techniques have made gravity dams an economically competitive alternative to embankment structures. The following factors tend to make RCC more economical than other dam types:

a. Material savings. Construction cost histories of RCC and conventional concrete dams show the unit cost per cubic yard of RCC is considerably less. The unit cost of concrete for both types of dam varies with the volume of the material in the dam. As the volume increases, the unit cost decreases. The cost savings of RCC increase as the volume decreases. RCC dams have considerably less volume of construction material than embankments of the same height. As the height increases, the volume versus height for the embankment dam increases almost exponentially in comparison to the RCC dam. Thus, the higher the structure, the more likely the RCC dam will be less costly than the embankment alternative.

b. Rapid construction. The rapid construction techniques and reduced concrete volume account for the major cost savings in RCC dams. Maximum placement rates of 5,800 to 12,400 cubic yards/day have been achieved. These production rates make dam construction in one construction season readily achievable. When compared with embankment dams, construction time is reduced by 1 to 2 years. Other benefits from rapid construction include reduced construction administration costs, earlier project benefits, and possible selection of sites with limited construction seasons. Basically, RCC construction offers economic advantages in all aspects of dam construction that are related to time.

c. Spillways and appurtenant structures. The location and layout alternatives for spillways, outlet and hydropower works, and other appurtenant structures in

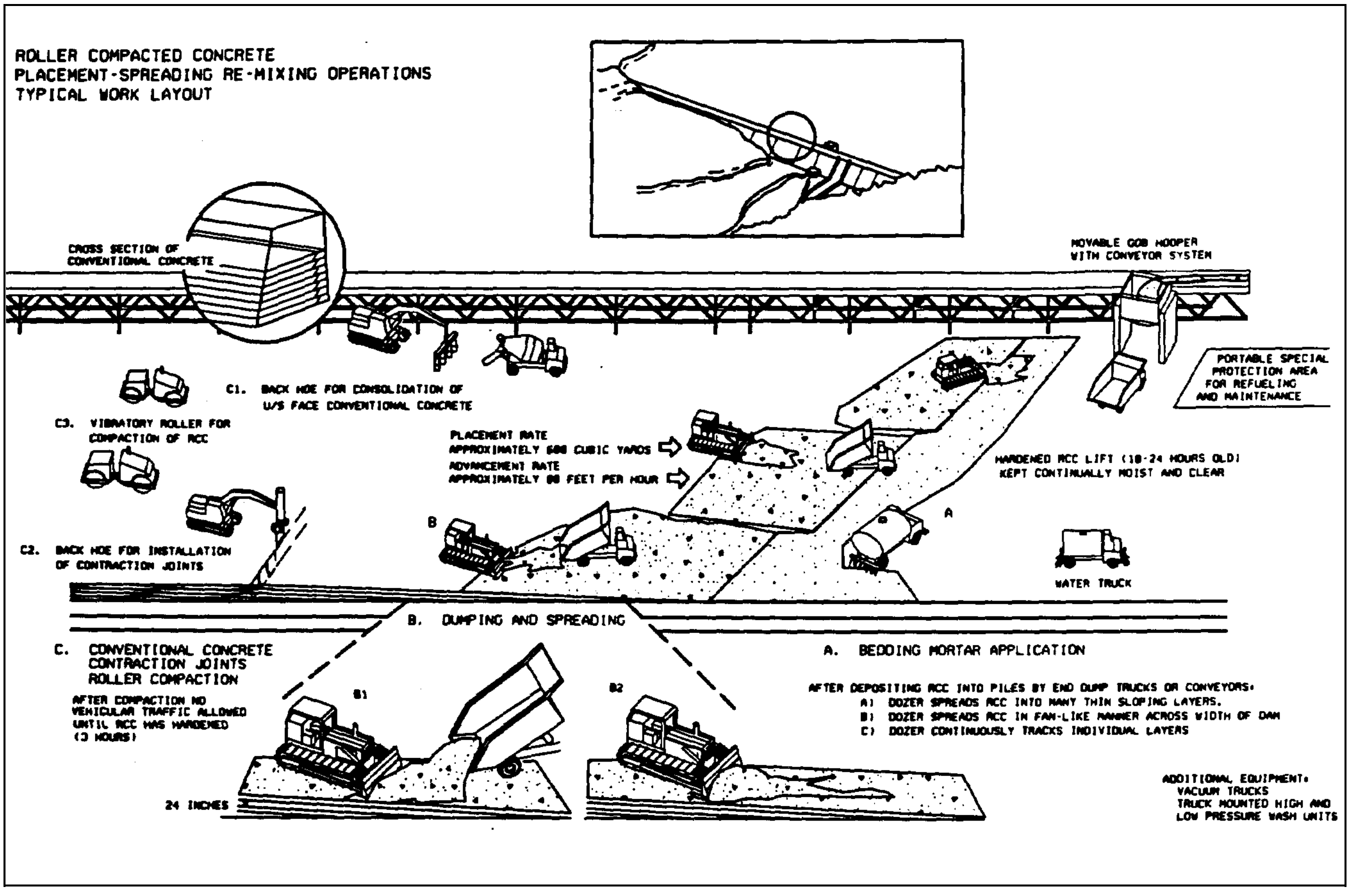

Figure 9-2. Typical work layout for RCC placement spreading operation

RCC dams provide additional economic advantages compared with embankment dams. The arrangements of these structures is similar to conventional concrete dams, but with certain modifications to minimize costly interference to the continuous RCC placement operation. Gate structures and intakes should be located outside the dam mass. Galleries, adits, and other internal openings should be minimized. Details on the layout and design of spillways and appurtenant structures are discussed in paragraph 9-4. Spillways for RCC dams can be directly incorporated into the structure. The layout allows discharging flows over the dam crest and down the downstream face. In contrast, the spillway for an embankment dam is normally constructed in an abutment at one end of the dam or in a nearby natural saddle. Generally, the embankment dam spillway is more costly. For projects that require a multiple-level intake for water quality control or for reservoir sedimentation, the intake structure can be readily anchored to the upstream face of the dam. For an embankment dam, the same type of intake tower is a freestanding tower in the reservoir or a structure built into or on the reservoir side of the abutment. The economic savings for an RCC dam intake is considerably cheaper, especially in high seismic areas. The shorter base dimension of an RCC dam compared with an embankment dam reduces the size and length of the conduit and penstock for outlet and hydropower works.

d. Diversion and cofferdam. RCC dams provide cost advantages in river diversion during construction and reduce damages and risks associated with cofferdam overtopping. The diversion conduit will be shorter compared with embankment dams. With a shorter construction period, the size of the diversion conduit and cofferdam height can be reduced. These structures may need to be designed only for a seasonal peak flow instead of annual peak flows. With the high erosion resistance of RCC, if overtopping of the cofferdam did occur, the potential for a major failure would be minimal and the resulting damage would be less.

e. Other advantages. The smaller volume of an RCC dam makes the construction material source less of a driving factor in site selection of a dam. Furthermore, the borrow source will be considerably smaller and more environmentally acceptable. The RCC dam is also inherently safer against internal erosion, overtopping, and seismic ground motions.

9-4. Design and Construction Considerations

a. Watertightness and seepage control. Achieving watertightness and controlling seepage through RCC dams are particularly important design and construction considerations. Excessive seepage is undesirable from the aspect of structural stability and because of the adverse appearance of water seeping on the downstream dam face, the economic value associated with lost water, and possible long-term adverse impacts on durability. RCC that has been properly proportioned, mixed, placed, and compacted should be as impermeable as conventional concrete. The joints between the concrete lifts and interface with structural elements are the major pathways for potential seepage through the RCC dam. This condition is primarily due to segregation at the lift boundaries and discontinuity between successive lifts. It can also be the result of surface contamination and excessive time intervals between lift placements. Seepage can be controlled by incorporating special design and construction procedures that include contraction joints with waterstops making the upstream face watertight, sealing the interface between RCC layers, and draining and collecting the seepage.

b. Upstream facing. RCC cannot be compacted effectively against upstream forms without the forming of surface voids. An upstream facing is required to produce a surface with good appearance and durability. Many facings incorporate a watertight barrier. Facings with barriers include the following:

(1) Conventional form work with a zone of conventional concrete placed between the forms and RCC material.

(2) Slip-formed interlocking conventional concrete elements. RCC material is compacted against the cured elements.

(3) Precast concrete tieback panels with a flexible waterproof membrane placed between the RCC and the panels.

A waterproof membrane sprayed or painted onto a conventional concrete face is another method; however, its use has been limited since such membranes are not elastic enough to span cracks that develop and because of concerns about moisture developing between the membrane and face and subsequent damage by freezing.

c. Horizontal joint treatment. Bond strength and permeability are major concerns at the horizontal lift joints in RCC. Good sealing and bonding are accomplished by improving the compactibility of the RCC mixture, cleaning the joint surface, and placing a bedding mortar (a mixture of cement paste and fine aggregate) between lifts. When the placement rate and setting time of RCC are such that the lower lift is sufficiently plastic to blend and bond with the upper layer, the bedding mortar is unnecessary; however, this is rarely feasible in normal RCC construction. Compactibility is improved by increasing the amount of mortar and fines in the RCC mixture. The lift surfaces should be properly moist cured and protected. Cleanup of the lift surfaces prior to RCC placement is not required as long as the surfaces are kept clean and free of excessive water. Addition of the bedding mortar serves to fill any voids or depressions left in the surface of the previous lift and squeezes up into the voids in the bottom of the new RCC lift as it is compacted. A bedding mix consisting of a mixture of cement paste and fine and 3/8-in.-MSA aggregate is also applied at RCC contacts with the foundation, abutment surfaces, and any other hardened concrete surfaces. EM 1110-2-2006 contains additional guidance on this issue.

d. Seepage collection. A collection and drainage system is a method for stopping unsightly seepage water from reaching the downstream face and for preventing excessive hydrostatic pressures against conventional concrete spillway or downstream facing. It will also reduce uplift pressures within the dam and increase stability. Collection methods include vertical drains with waterstops at the upstream face and vertical drain holes drilled from within the gallery near the upstream or downstream face. Collected water can be channeled to a gallery or the dam toe.

e. Nonoverflow downstream facing. Downstream facing systems for nonoverflow sections may be required for aesthetic reasons, maintaining slopes steeper than the natural repose of RCC, and freeze-thaw protection in severe climate locations. Facing is necessary when the slope is steeper than 0.8H to 1.0V when lift thickness is limited to 12 inches or less. Thicker lifts require a flatter slope. Experience has demonstrated that these are the steepest uncompacted slopes that can be practically controlled without special equipment or forms. The exposed edge of an uncompacted slope will have a rough stair-stepped natural gravel appearance with limited strength within 12 inches of the face. Downstream facing systems include conventional vertical slipforming placement and horizontal slipforming similar to that used on the upstream face. When this type of slope is used, the structural cross section should include a slight overbuild to account for deterioration and unraveling of material loosened from severe weather exposure over the project life (see Figure 9-3). Several recent projects have compacted downstream faces using a tractor-mounted vibrating plate.

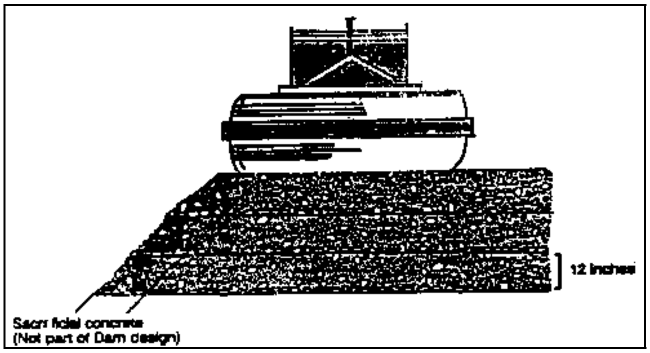

Figure 9-3. Compaction of RCC at downstream face

f. Transverse contraction joints. Transverse contraction joints are required in most RCC dams. The potential for cracking may be slightly lower in RCC because of the reduction in mixing water and reduced temperature rise resulting from the rapid placement rate and lower lift heights. In addition, the RCC characteristic of point-to-point aggregate contact decreases the volume shrinkage. Thermal cracking may, however, create a leakage path to the downstream face that is aesthetically undesirable. Thermal studies should be performed to assess the need for contraction joints. Contraction joints may also be required to control cracking if the site configuration and foundation conditions may potentially restrain the dam. If properly designed and installed, contraction joints will not interfere or complicate the continuous placement operation of RCC. At Elk Creek Dam, contraction joints were installed with no impact to RCC placement operations by inserting galvanized steel sheeting into the uncompacted RCC for the entire thickness and height of the dam. The sheets were pushed vertically into the RCC by means of a tractor-mounted vibratory blade, as shown in Figure 9-4.

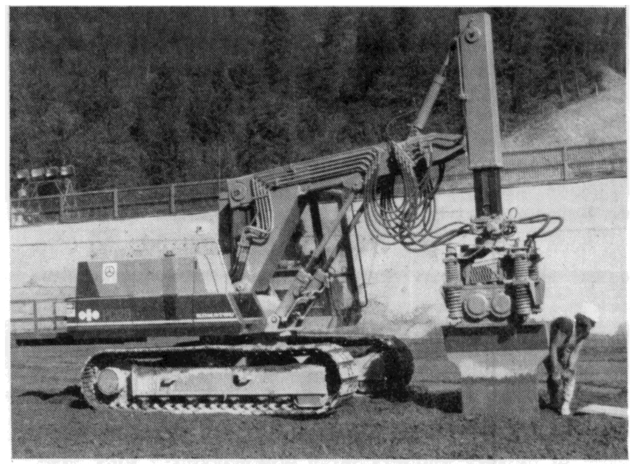

Figure 9-4. Contract joint placement using a vibrating blade to insert galvanized steel sheeting

g. Waterstops. Standard waterstops may be installed in an internal zone of conventional concrete placed around the joint near the upstream face. Waterstops and joint drains are installed in the same manner as for conventional concrete dams. Typical internal waterstops and joint drain construction in RCC dams are shown in Figure 9-5. Around galleries and other openings crossing joints, waterstop installation will require a section of conventional concrete around the joint.

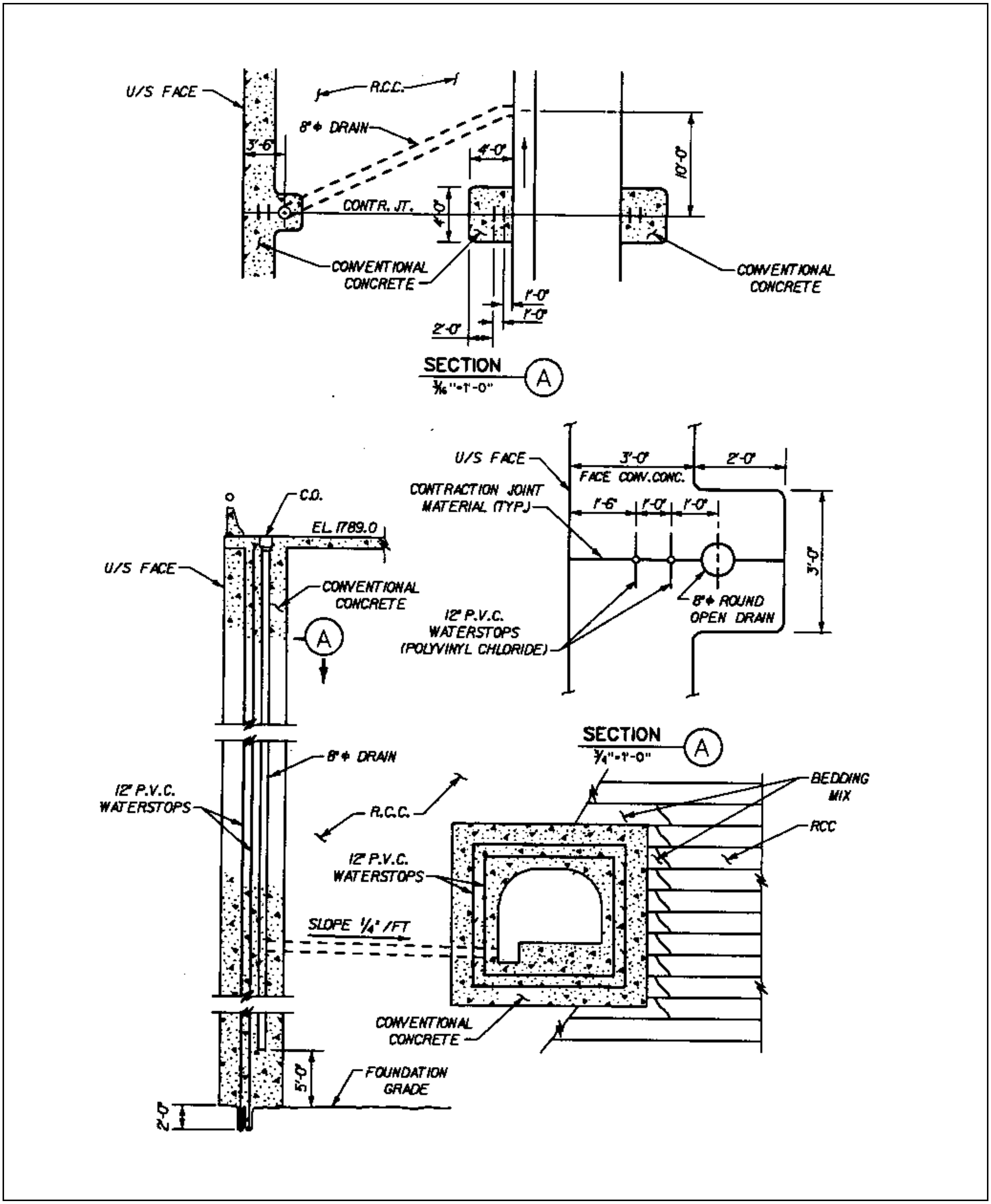

Figure 9-5. Typical internal waterstops and joint drain construction in RCC dams

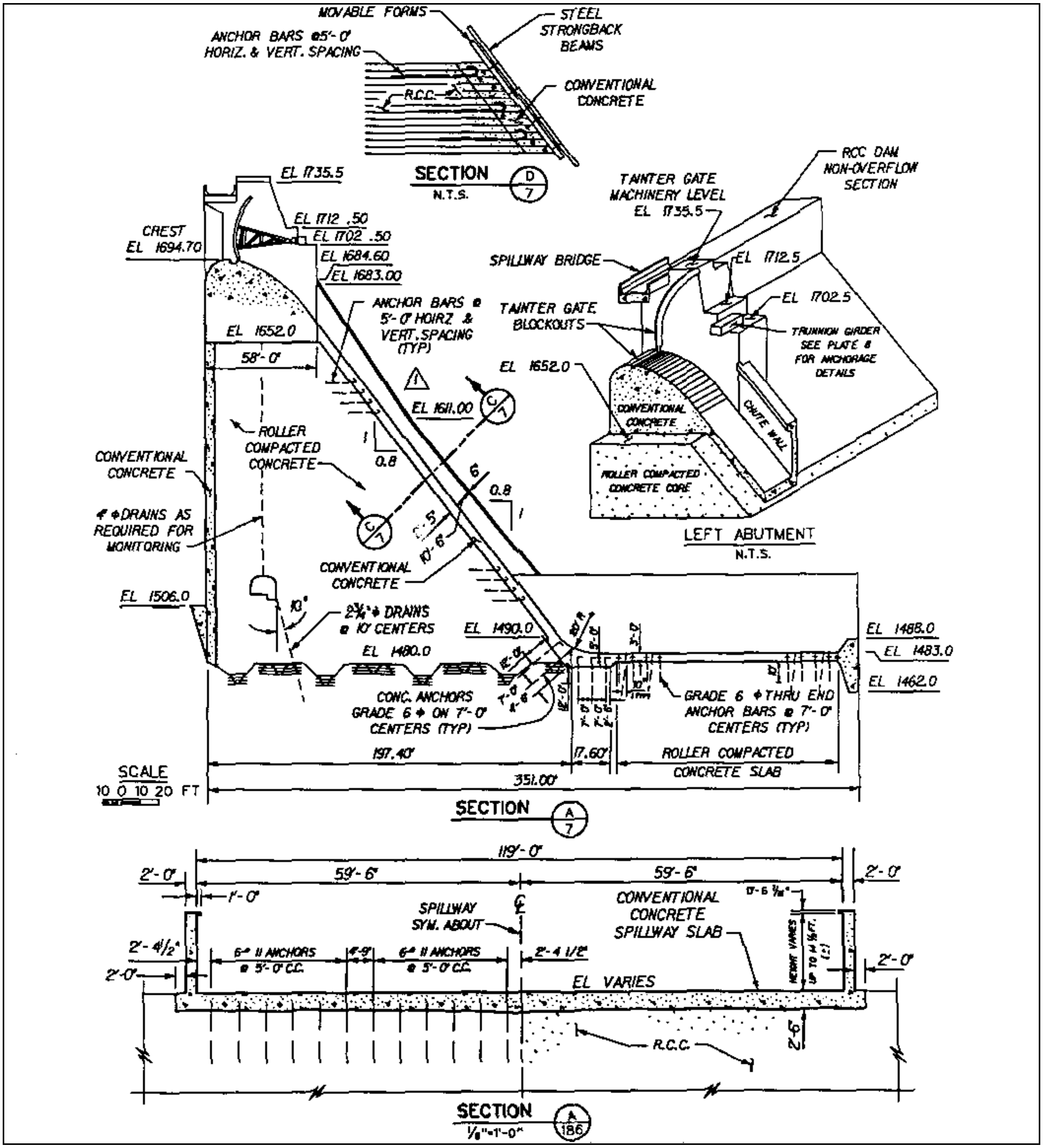

Figure 9-6. RCC spillway details